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Modeling GMPLS and optical MPLS networks

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Abstract

A consequence of migrating the existing Internet architecture to an all-optical one is that the network will consist of a mixture of equipment, ranging from electrical routers to all-optical packet switches. Hence, future networks will consist of multiple domains employing different technologies. The MPLS concept is attractive because it can work as a unifying control structure covering all technologies. This paper describes how a novel scheme for optical MPLS and circuit switched GMPLS based networks can incorporated in such multi-domain, MPLS-based scenarios and how it could be modeled. Network nodes supporting GMPLS the proposed novel scheme is implemented and routing and path setup is demonstrated.

Introduction

In the old days, the vision was to create one single technology for multi service networks. This was one of the drivers behind developing and deploying ATM. However, the technologies being developed today are of a different nature. It is no longer likely with a network based on one single technology, simply because the vast amount of equipment in e.g., the global Internet makes instant upgrade/replacement impossible. Migration to future technologies will be seen as islands popping up and this gradual upgrade creates heterogeneous networks consisting of a number of different technologies. Currently, for instance, optical technologies are being introduced into the networks, but electrical routers/switches are still present. Thus, the networks of the future will be multi technology, multi service networks as sketched in Figure 1. Add to that the requirements of traffic engineering capabilities and you will end up with a very complex network.

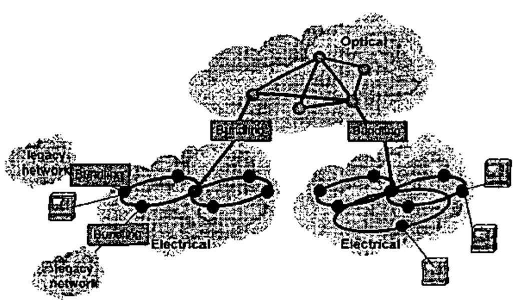

Figure 1: A multi-domain network comprising different technologies

This has had an impact on the structure of modern networks, but also this has created a requirement for special adaptation devices that are able to propagate traffic between network domains running different technologies and for a common control plane structure able to unify all these technologies and create a useful network. A closer look at the adaptation devices can be found in [Chr2001]. In this paper the emphasis is on the control part of the network.

This paper is organized as follows. Firstly, a brief MPLS tutorial is provided. Then the limitations for introducing optical MPLS are reviewed, and two possible approaches are presented. One is a novel approach, which avoids header modification, and the other is GMPLS. The integration of those technologies is treated and it is described how to model these combined MPLS / GMPLS networks. The GMPLS as well as the optical MPLS OPNET model are then presented along with some simulation results that verify the functionality and illustrate how the models interoperates with the build in OPNET MPLS model.

MPLS based concepts

This section introduces the MPLS networking concept suitable for electrical packet switching. The use of the MPLS concept with all-optical network nodes is considered and a novel scheme and the GMPLS concept is presented as solutions to the faced problems.

Basic properties of MPLS

MPLS [Ros2001a] is a networking concept that is based mainly on a shift of all complex functionality to the edge of the network, leaving only simple operation for the core network and hence enabling fast and efficient operation. The control plane (that takes care of e.g. routing) and switching (packet forwarding) are completely decoupled, which yields the advantageous property that they can be chosen independently. This is the main reason why we in this paper can consider routing and structural issues without treating e.g., packet forwarding explicitly. MPLS is designed as a pure 'everything over everything' concept, hence its name. In reality, however, its predominant use and the majority of standardization work are focused on carrying IP traffic with MPLS, which is due to the importance of the ubiquitous Internet. In MPLS packets are forwarded along routes called Label Switched Paths (LSPs) that may be determined by routing protocols based on predefined traffic classes called Forward Equivalent Classes (FECs). An FEC can be equivalent to a single entry in a conventional IP routing table or it can be an aggregation of multiple entries. An FEC can also be specified based on a number of additional constraints such as originating address, receiving port number and QoS parameters. These LSPs are defined in the switches by using labels, which are distributed by a Label Distribution Protocol (LDP) responsible for mapping between routing and switching. The MPLS standard doesn't specify one specific label distribution protocol; it just highlights the required properties. Currently, four protocols of which two are new and two are modifications of existing protocols are mentioned in the standards [And2001][Rekh2000][Jamo1999][Brad1997].

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One of the major benefits of the MPLS concept is its ability to perform traffic engineering, i.e., to be able to control how traffic flows through the network, which is one of the prerequisites for providing QoS guarantees on connections. Generally, traffic engineering implies to route along non-shortest paths and utilizes Constraint Based Routing (CBR) where the routes are calculated subject to performance- and administrative constraints, which are assigned by the network management system, based on e.g., traffic measurements.

In MPLS, switches are generally called Label Switch Routers (LSRs). Ingress edge LSRs take care of attaching short, fixed length labels to packets when they enter the MPLS domain, which includes the non-trivial task of determining to which FEC a given packet belongs. Within the core of the network forwarding will be based on the label only, and before leaving the MPLS domain packets have their label removed by the egress edge LSR, as it is sketched in Figure 2.

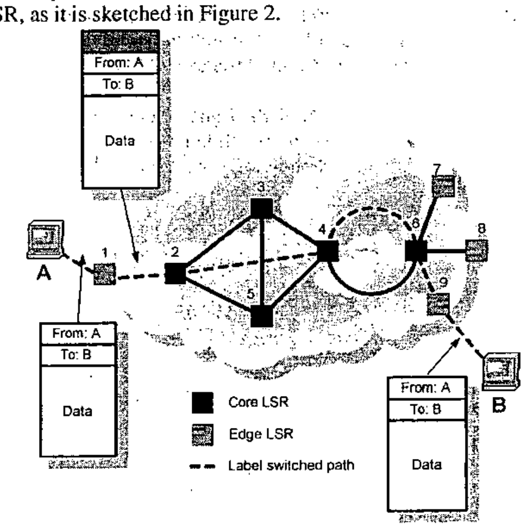


Figure 2: The label is used only within one MPLS domain. By attaching different labels at the ingress LSR, different routes through the network for the same destination can be selected, which allows for traffic engineering.

The labels are generally not kept constant along an LSP and thus a path through the network is defined by a sequence of labels, all of which are assigned by the LDP. Within the core switches only the labels are examined, and what distinguishes this method from that of conventional IP routing are the loose coupling between the label and the destination address as well as the lookup scheme within the switches themselves. The labels used by MPLS require exact match in the lookup tables, which is a much simpler operation than LPM [Rekh1995]. I.e., OSPF would build a routing table is each LSR and based on this information and possibly additional information the label distribution protocol builds another table in which the *label* is used as the key. The outcome of a table lookup is information about outgoing port number and the outgoing label, which is used to replace the label contained within the packet as well as expediting the packet to the designated output port. The label replacement operation is usually called *label swapping* and is the most common packet modification operation in MPLS. In addition, when working with multiple domains in a network, the single label might be replaced by a stack of labels with only the top label being used within one particular domain. At domain boundaries label swapping is insufficient and must be exchanged for more complex operations such as label pushing and popping.

Optical MPLS

MPLS was designed for packet switched networks. However, when considering all-optical devices, packet switching using header modification is not yet a mature technology. Even though switching of optical signals potentially is done with very high bit rates [Dan1997, Hun2000, Chi1998], the approach is facing several problems. Regeneration of the signal through 2R or 3R regeneration is required if several switches are cascaded [Wol1999] and buffering of packets and optical label swapping are two challenges that are only solved in the labs, even though attempts have been done to reduce the buffer requirements by utilizing the wavelength dimension [Dan1997].

Key identification

As previously described, header modification is a main technological limitation for introducing optical MPLS network. This problem is addressed in the key identification scheme [Wess001][Chr2002], where the requirements to the optical layer are reduced. The concept of the scheme is shown in Figure 3, for a network comprising two edge nodes and three core nodes. Each node is initially assigned a unique so-called key.

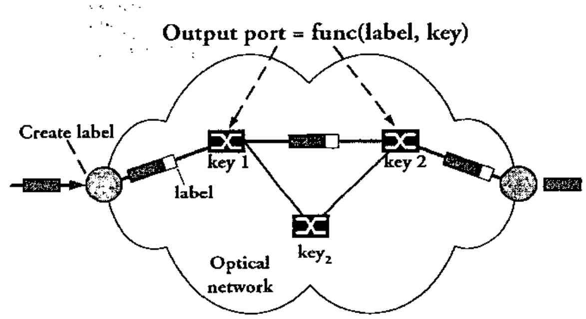


Figure 3: Concept of the key identification approach. The label, created at the edge node, is used together with a mathematical function to identify the output port in each core MPLS node.

It is desired to route the packet through the core nodes represented with key 1 and key 2. This is achieved by creating a label at the ingress node, and by using this label and the node specific keys each core node calculates the outgoing port by a function on the label and the key.

The mathematical function is based on the *Chinese Remainder Theorem* [Cormen], which states that – with some restrictions – it is possible to define two independent arrays of integers of same length and combine those to a single scalar, which we will use as the label.

Then, by a simple modulo function on the label (the scalar) and an integer from the first array, the result is the value from the other array. Hence, by defining the first array as the keys for the nodes along the path and the second array as the desired output ports for the nodes, then the label is created and at each node the correct output port is simply calculated. The only restriction is that all the keys should be pair-wise relative primes.

As the same label is used at all the nodes, it is not necessary to modify the header along the path. Hence, optical header modification is avoided as the label is only created and removed at the edge LSRs. The scheme differs from "normal" MPLS as the full switching information is carried within the header. This might reduce the scalability of the scheme for very large network sizes, but on the other hand the use header modification and maintenance of an LDP is avoided.

GMPLS

GMPLS is a generalization of MPLS that allows a seamless integration of a multitude of technologies, especially circuit switched systems, with packet switched networks. Thus, interfacing with traditional telecom TDM systems (e.g. SONET / SDH) and wavelength routed optical networks is possible with the use of GMPLS. GMPLS is in widespread use and have been implemented by several manufacturers [Ber2002].
In contrast to optical packet switching technologies, the technologies for optical circuit switching are far more accessible in the core network. By using mixed-technology, multi domain networks the advantages of different technologies can be combined. The problem is normally that a unified control and management structure is lacking. However, by integrating MPLS, key-MPLS and GMPLS a number of advantages are significant. The integration is depicted in Figure 4 where the big cloud denotes the MPLS based domain and the smaller clouds are islands of key-MPLS and GMPLS sub-domains.

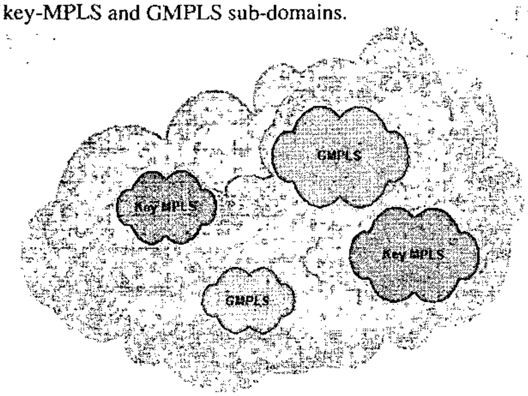


Figure 4: GMPLS in a typical usage scenario where GMPLS is used as 'islands' in the network.

A unified control and management structure can be used for the full cloud. This enables support of traffic engineering even though different underlying physical layers are used. Furthermore the advantages for both circuit- and packet switched networks is combined, which is advantageous as it offers:

- Traffic engineering capabilities,
- High capacity core
- Flexible, controllable edge
- Protocol independence (i.e., e.g. IP interoperability)

Hence GMPLS for circuit switched networks while allowing a management structure similar to standard MPLS.

Modeling and integration

The models in this paper have been made with OPNET modeler 8.0 and the MPLS model suite. The MPLS model has been extended and modified in order to create GMPLS and key-ID network elements.

Modeling GMPLS

Real GMPLS networks are highly complex and may cover devices such as optical wavelength switches and SONET network nodes, i.e. GMPLS can operate with as well electronic as optical technologies. Hence, GMPLS networks can get very complex since a multitude of technologies are hidden there, implying a vast number of protocols, devices and configuration options. The real-life network must be simplified greatly in order to be able to build a model that can produce results within an acceptable timeframe. A brute-force modeling methodology that just tries to model the real network in every detail is inappropriate. Below the goals for the simulation are identified and based on that the simplified simulation model can be set up. Obviously, the model must be simple enough to achieve the identified goals, while representing a fair model of the real network.

Requirements to the model

The goal of this simulation study is to build a model of how GMPLS interacts with an MPLS based network. With the model it should be possible to measure/study:

- Call setup probability
- Optical signal quality
- Network topology / routing issues
- Label length (when model is used for key-MPLS)

A list of input parameters is provided below:

Attribute	Description
Topology generation parameters	
- Number of nodes	Size and connectivity of the network
- Number of links	
- Maximum distance	
Path constraints	Bandwidth constraints
Type of network	SONET / pure optical

OPNET implementation

The MPLS model has been extended/modified in order to create a GMPLS network element that can be built into MPLS network. This GMPLS models element represents the entire GMPLS network, i.e. a complete topology can be built with this single node. Figure 4 illustrates how the GMPLS network can interoperate with MPLS devices, i.e., LSPs can be setup through the GMPLS domain in this mixed environment. .

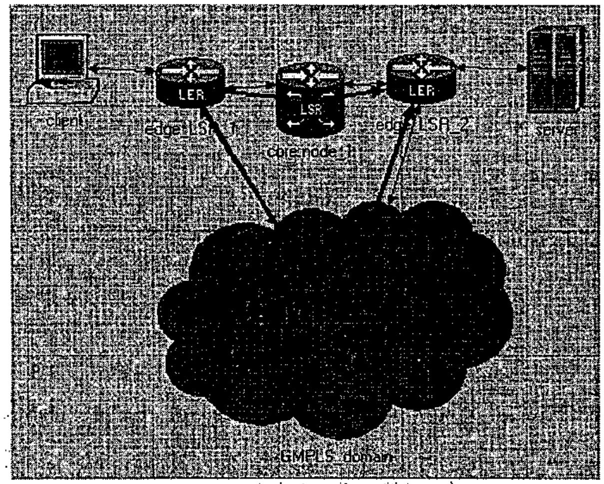


Figure 5: A GMPLS model, which can interoperate with MPLS, has been built into OPNET.

More details of the implemented model.
In order to minimize the modifications needed in the OPNET code, GMPLS has been implemented as a separate process within the network nodes. The LDP process has then just been modified to detect whether this GMPLS process is present or not (and hence whether this is a MPLS or GMPLS node)

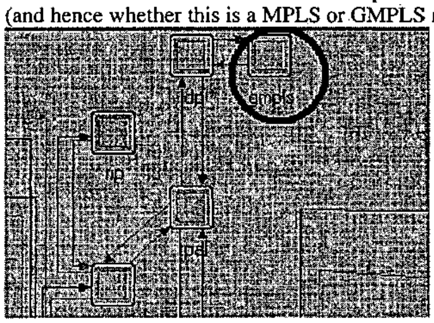


Figure 6: GMPLS has been implemented as a separate process in the MPLS node model

The details of the process model is shown below (figure 6)

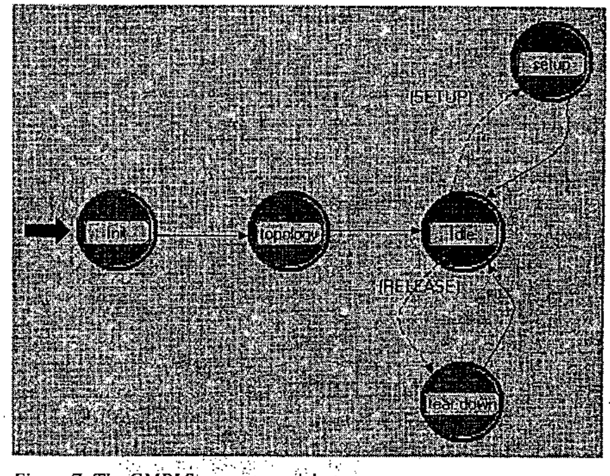


Figure 7: The GMPLS process model

Topology generation is performed by using the *Route package* in OPNET. The GMPLS implementations allows for either topology import from a file or generation of arbitrary topologies based on a specification of the networks size (number of nodes and links). Modeling network topologies has been studied by a number of researchers [Zeg1996] [Fen2000] and it has been shown that the topologies have an impact on the network behavior. The topologies generated are suited to model an optical WDM network, i.e. the capacities of each link is given as a number of wavelengths. The actual capacity (i.e., bit rate) of each wavelength is not modeled explicitly. This is not necessary when path setup is considered as in this study.

The setup state tries to find a route through the network. One path requires one available wavelength from source to destination node. An attempt is made to find the shortest possible path though the network. This minimizes the overall capacity consumption of the oath and moreover (id the network is build from optical cross-connects) maximizes the signal quality. If the network possesses insufficient resources, the setup request is rejected.

Release request causes all resources associated with a given path to be released and they thus become available for future call setup requests.

Simulation results

This section contains results from simulations on the GMPLS model.

Now, let's try to arbitrarily generate network topologies. The results shown below are obtained for a network consisting of 20 nodes randomly (uniformly distributed) interconnected by 40 links. In total approximately 1750 setup requests were sent to this network. The paths are then active for a random time and then torn down.
Figure 8 shows the number of LSPs in the network. Paths setup is accomplished in the following way: The edge of the GMPLS domain receives the setup request from the surrounding MPLS network. Then an attempt is made to route the call though the GMPLS domain is made. To mimic all kinds of setup requests,

two nodes in the GMPLS network are chosen at random and then an attempt to find a route to the destination is made.

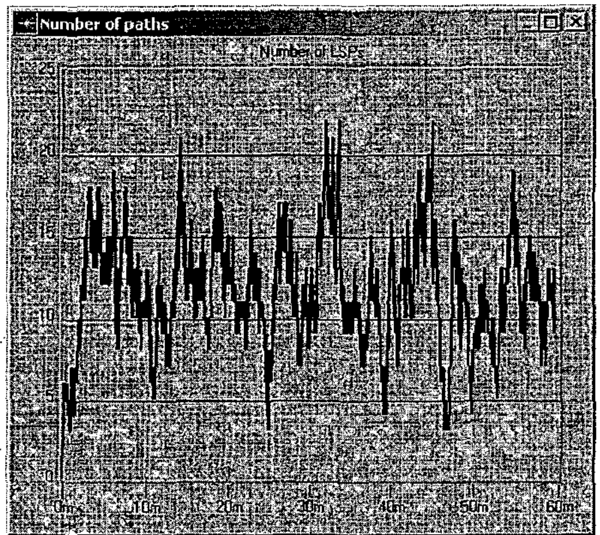


Figure 8: The number of established LSPs varies during the simulation.

In case no route exists the call is blocked, i.e., there is always a chance of a connection setup request being rejected. Figure 9 shows the rejection probability (rejected call / setup requests) for this network. Obviously the calculated probability gets more and more accurate with increasing number of calls. As can be seen, after 20 minutes, initial transients have gone. Hence to obtain a useful value for the call rejection probability at least 20 minutes should be simulated.

The path length varies depending on traffic load and network topology. The length (in number of hops) of the route impacts the OSNR of the signal. Hence for some OXC technologies, there can be an additional constraint (in addition to bandwidth requirements) on the path length. Figure 12 shows that for this particular network the path length varies from 2 to 7 hops.

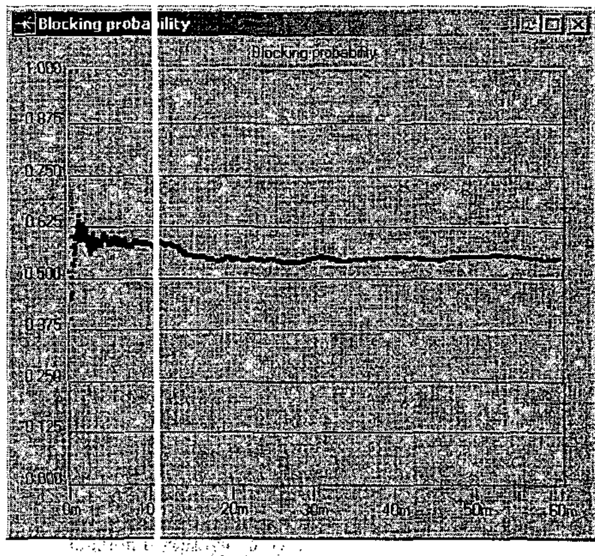


Figure 9: The rejection (blocking) probability for a network consisting of 20 nodes and 40 links.

If the size of the network is varied the results are as shown below (mean number of paths or LSPs, rejected calls and path length). In the simulations, networks with between 10 and 30 nodes were generated. All simulations are bases on approximately 500 call setups (per network size). Each graph is based on 55 simulations.

Figure 10 shows how the average number of simultaneous paths (LSPs) in the network depends on the network size. As the number of calls is the same for all scenarios, these results are directly comparable to the rejection probability shown below (figure 14). Clearly, lower rejection probability implies more LSPs.

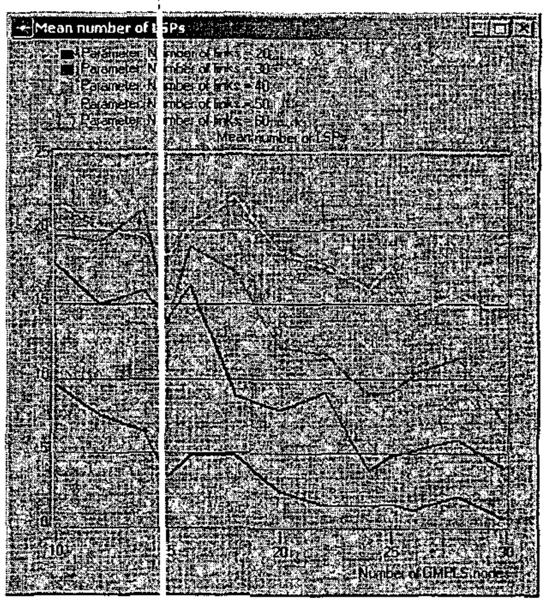


Figure 10: Average number of LSPs through networks of various sizes.

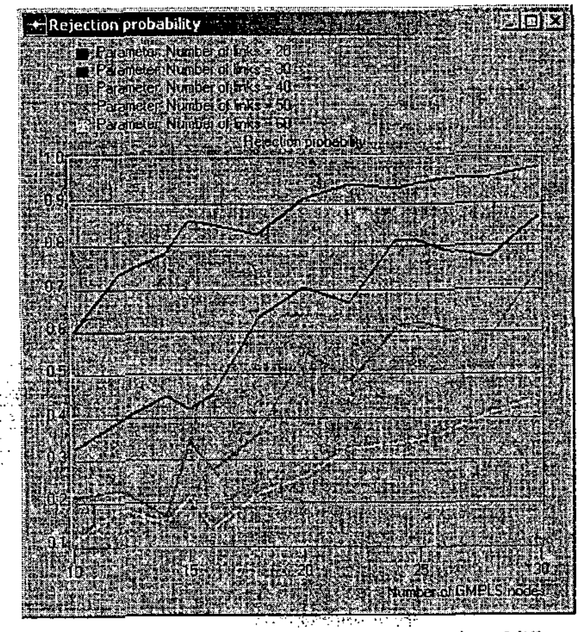


Figure 11: Rejection (blocking) probability for a number of different network sizes.

The GMPLS model has been integrated with the OPNET MPLS models. Figure 12 shows a scenario where GMPLS is used is the core of a MPLS network.

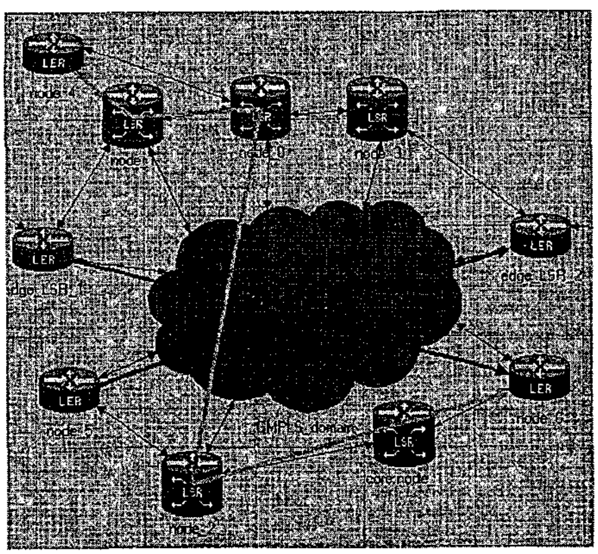


Figure 12: The GMPLS models are fully integrated with the OPNET MPLS models.

MPLS setup request are propagated to all involved nodes by the LDP protocol. The GMPLS model responds to these setup request by setting up a path. GMPLS path setups are reported in the OPNET simulation log. Hence an end-to-end path can cross as well MPLS and GMPLS domains in the network. In a typical scenario, where GMPLS is used in the core, the path will thus be MPLS-GMPLS/key-MPLS-MPLS.

Modeling the Key MPLS scheme

The scalability of the scheme is evaluated through simulation of randomly connected networks of various sizes.
The result is shown in Figure 13, where the average and the maximum values represent typical and worst-case values, respectively. It is shown that a label length of about 2 bytes is sufficient to support network sizes of up to 10 all-optical network nodes. Larger networks will generally require longer paths, which are infeasible without optical regeneration.

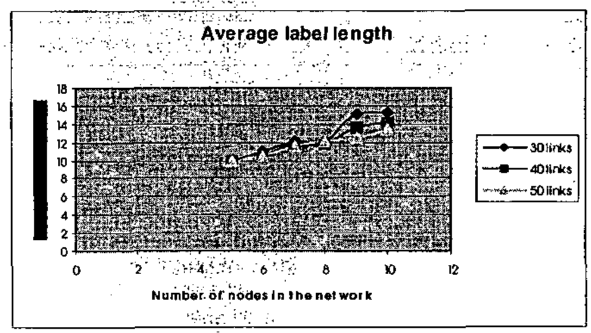
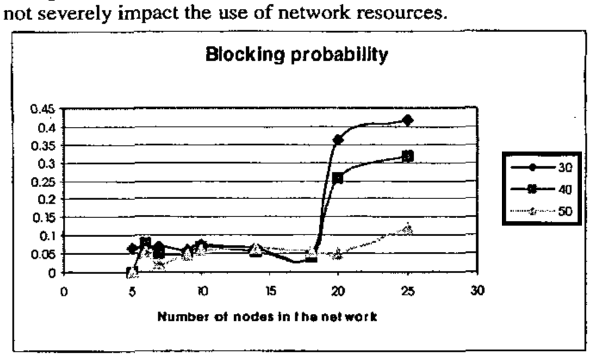


Figure 13: Required size of label field for different network sizes.

Clearly the length increases with networks size, but interestingly enough the length is appropriate for optical networks and does not severely impact the use of network resources.



Conclusion

GMPLS is becoming more and more widely used as a control plane in optical circuit switched networks. Combining GMPLS with MPLS (which in itself can seamlessly integrate a number of packet switched technologies, regardless of protocol) yields an interesting network architecture, which is rather future proof.
In this paper a model of such mixed MPLS, GMPLS network has been presented. Path setup through MPLS and GMPLS has been demonstrated and impact of network size on e.g. call rejection probability has been measured. Furthermore simulation on a novel packet forwarding scheme for optical MPLS networks and

simulation results are presented that shows the feasibility of this scheme.

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